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Status Update: Modeling Energy Balance in NIF Hohlraums

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Status Update: Modeling Energy Balance in NIF Hohlraums*

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Summary:

- We have developed a standardized methodology to model hohlraum drive in NIF experiments.
- We compare simulation results to experiments by 1) comparing hohlraum x-ray fluxes and 2) comparing capsule metrics, such as bang times.
- Long-pulse, high gas-fill hohlraums require a 20-28% reduction in simulated drive and inclusion of ~15% backscatter to match experiment through (1) and (2).
- Short-pulse, low fill or near-vacuum hohlraums require a 10% reduction in simulated drive to match experiment through (2); no reduction through (1).
- Ongoing work focuses on physical model modifications to improve these matches.

We have developed a standardized methodology to model hohlraum drive in NIF experiments. Motivated by NIF 2009 vacuum hohlraum data [1], Omega Au sphere experiments [2], and gas-filled ignition scale hohlraum SRS spectra [3], we utilize a High Flux Model (HFM) [4] which uses a DCA NLTE model for the hohlraum wall at high temperatures and STA-based LTE opacity tables at low temperatures with flux-limited electron heat transport with a limiter of 0.15. Standard 2D HYDRA hohlraum calculation use 85 photon energy groups, 34,000 zones, and 5 million photon particles, 2.5° polar zoning, 65 radial zones in the DT fuel (gas and solid), 220 radial zones in the ablator, and 90 radial zones in the wall (70 in first 10 μm, innermost zone 40 Å).

We compare simulation results to experiments by 1) comparing hohlraum x-ray fluxes and 2) comparing capsule metrics, such as bang times. X-ray flux measured by the DANTE x-ray diode array is compared to synthetic DANTE signals from post-processed 2D or 3D integrated hohlraum-capsule simulations. The DANTE diagnostic incorporates 18 energy band channels, and we make comparisons to the flux from a reconstructed fit using all channels and to individual channel voltages.

Two subtleties complicate this comparison. First, the DANTE instrument views some of the laser spots and un-illuminated wall, but also views the outside of the target, which intercepts unconverted laser light and produces low-energy x-rays. This unconverted light signal is not present in the simulations and can be a significant error at 80 eV (low-foot drive), but is a small error at 300 eV peak drive. Secondly, for long pulses, the LEH wall material blows in and starts to become opaque to the x-ray flux produced inside the hohlraum, thus making the LEH effectively smaller.

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Calculating the DANTE signal correctly depends on getting both the internal radiation temperature and the effective LEH size correct.

(2) The time of capsule peak emission (bang time) provides a sensitive measurement of the x-ray drive inside the hohlraum, and we compare simulated to measured bang times to infer any drive discrepancy. A complication is that matching bang time also depends on correctly modeling the capsule response to the drive, which depends on opacity and EOS of the ablator material.

Long-pulse, high gas-fill hohlraums require a 20-28% reduction in simulated drive and inclusion of 15% backscatter to match experiment through (1) and (2). The HYDRA HFM described above applied to gas-filled hohlraums (0.96 – 1.6 mg/cc He) heated by long (15-20 ns) pulses predicts bang times 500-700 ps earlier than measured (Fig. 1). Calculations show a sensitivity of ~25 ps in bang time per percent of peak flux, implying that this delay is could be equivalent to ~20-28% less peak drive than predicted. This reduction is in addition to ~15% measured laser backscatter, which also reduces drive.

To determine whether this modeling discrepancy was due primarily to the capsule response or the hohlraum drive, a special "viewfactor" hohlraum experiment was developed [5]. In this experiment we remove one LEH to provide an unobstructed view of the radiation drive and reduce sensitivity to LEH closure, and replace the capsule by a thin shell which burns through to provide analogous back pressure to the wall. This experiment showed that the drive through the open end was ~20% lower than predicted by LASNEX HFM calculations (Fig. 2), confirming that the bang time discrepancy was primarily due to radiation drive modeling.

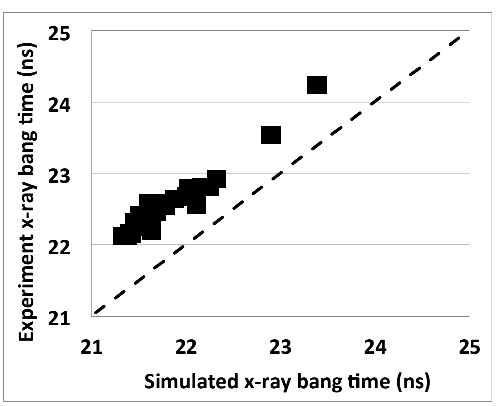

Fig 1: Measured bang times ~500 ps early compared to HFM calculations

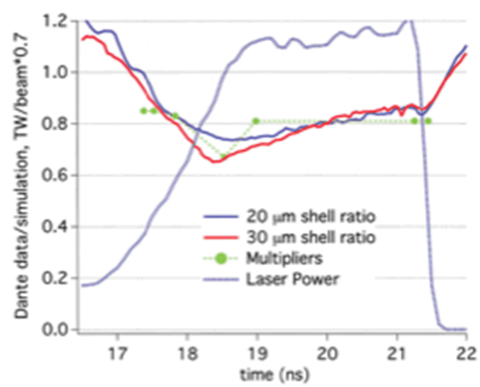

Fig 2: Measured drive is ~20% lower than HFM calculations, consistent with bang time discrepancy

Short-pulse, low fill or near-vacuum hohlraums require a 10% reduction in simulated drive to match experiment through (2); no reduction through (1). Standard HYDRA calculations are able to approximately match the total radiation drive and capsule bang time for the 2013 indirect drive exploding pusher (IDEP) [6], which had a 4 ns pulse and a near-vacuum (0.03 mg/cc) hohlraum fill. Simulations also approximately match the total DANTE flux (but not the exact spectrum) for high density carbon (HDC) ablator experiments driven by 6-9 ns pulses, with fill densities ranging from near-vacuum to 0.6 mg/cc, and having low backscatter (<3%). For example, Fig. 3 shows that the measured DANTE peak flux through the LEH of a 6.72-mm-diameter 0.6 mg/cc fill hohlraum is within 3% of the HYDRA HFM simulated value. However, HDC symcap experiments require a minimal adjustment (5-10% power removed from rise and peak) to match the bang times for 2-shock HDC pulses (Fig. 4). This slight inconsistency in the simulation match to flux and bang time suggests the HDC EOS or drive spectrum may require adjustment. It is also seen from these experiments that the drive discrepancy depends on hohlraum fill (and perhaps the level of SRS, which also depends on pulse duration and intensity). When the hohlraum fill density is increased for short 2-shock pulses, the backscatter increases and modeling discrepancy grows (Fig 4).

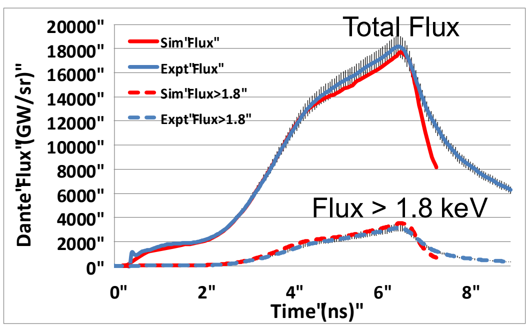

Fig 3: Comparison of simulated and measured DANTE flux for 0.6 mg/cc fill 6.72-mm diameter hohlraum

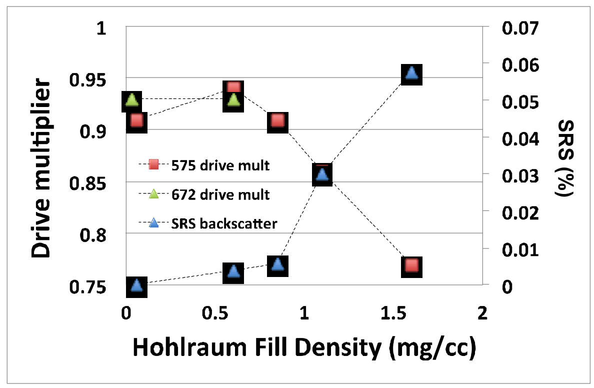

Fig 4: Peak power multiplier required to match bang time and inner cone SRS vs. hohlraum fill density

In Fig. 5, we compare energy accounting for a high foot CH implosion, which loses energy to backscatter and has significant drive multipliers, to the accounting for a 3-shock near-vacuum HDC implosion. Given the ~15% difference in backscatter and ~15% difference in peak drive multiplier, we see that for a given laser power there is ~30% more x-ray drive for the near-vacuum hohlraum.

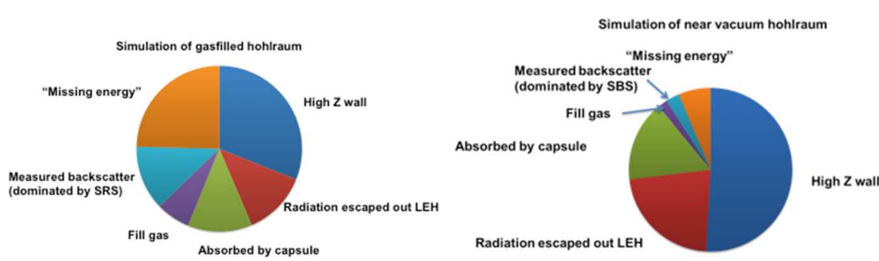

Fig 5: Hohlraum x-ray energy accounting for typical gas-filled hohlraum vs. a near-vacuum hohlraum

Ongoing work focuses on physical model modifications to natively lower the calculated x-ray drive. One promising avenue may be to adopt models that lower the calculated x-ray conversion efficiency by storing more energy in the hot corona. It is found that by invoking a flux limiter governed by the onset of a two-stream instability [7,8], the calculated flux and bang time can be brought closer to the data. There are also efforts underway to assess more detailed atomic physics models for the high-Z wall, to check the spatial, temporal, and energy group resolution of the HFM, and to check the consistency of various physics packages and model settings used in the various ICF design codes.

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